NOVEL HEAT TRANSFER DEVICE RESEARCH

Ryan E. Mikus

Advanced Structural Concepts Branch
Structures Division

Kenneth D. Kihm

University of Tennessee

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Interim Report

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AIR FORCE RESEARCH LABORATORY
AIR VEHICLES DIRECTORATE
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7542
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

NOTICE AND SIGNATURE PAGE

*//Signature//   //Signature//

RYAN E. MIKUS, 1st Lt, USAF   ANDREW D. SWANSON, Chief
Research Engineer   Advanced Structural Concepts Branch
Advanced Structural Concepts Branch   Structures Division
Structures Division

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Ryan E. Mikus (AFRL/RBSA)
Kenneth D. Kihm (University of Tennessee)

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14. ABSTRACT
Qu Tubes or Advanced Thermal Transport Devices (ATTD's) use a new heat transfer principal and are believed to be superior to standard heat pipes. Inventor claims that the ATTD's are entirely dry on the inside and consist of three thin layers of material and a powder. Other claims state that the ATTD's act independently of gravity, exhibit very high conductivity, work over large distances and temperature ranges, and operate at a lower pressure than traditional heat pipes. The Air Vehicles Directorate of Air Force Research Laboratory purchased Qu tubes and equipment to thoroughly examine the operation limits of such a device in a highly controlled environment.

15. SUBJECT TERMS
Qu tube, heat pipe, thermosyphon, advanced thermal transport device, solid state heat pipe

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1.0   RESEARCH OBJECTIVE

The main objective for this research is to validate the claims and performance of the Novel Heat Transfer Device (Qu Tubes) against conventional wicked and un-wicked heat pipes with water as the working solution.

2.0 PROPOSED TASKS

I.   Verification of the claim that there is no working fluid inside the Qu Tubes using high-resolution x-ray imaging.

II.   Qualitative characterization of the Qu Tube operations in comparison with a wicked water heat pipe using the IR thermography.

III.   Quantitative characterization of both Qu Tubes and water heat pipes using a sophisticated data acquisition system to verify the comparative performance of the two devices.

3.0   SUMMARY OF ACHIEVEMENT

3.1   X-Ray Verification of the Existence of Working Fluids Inside the Qu Tubes

The test articles include aluminum Qu Tubes of 5/8-inch and ½-inch diameters, manufactured by Posnett Corp., and copper wicked heat pipes of 5/8-inch and ½-inch diameters, manufactured by Thermacore Inc. All of the test articles are 3 ft in length.

The high-resolution X-ray imaging facility at the Air Force Research Laboratory (AFRL) Materials & Manufacturing Directorate at Wright-Patterson Air Force Base reviewed the existence of a working fluid inside the Qu Tubes. Despite the inventor's claim that the Qu Tubes are entirely dry on the inside, Fig. 1 clearly identifies the existence of a working fluid for all of our tested Qu Tubes. It is hypothesized that Qu Tubes are dependent on gravity. Therefore, it will be essential to examine various orientations of the Qu Tubes in evaluating their performance. The heights of the fluid meniscus range from 3.1" to 3.2" measured from the bottom end. Figure 2 shows the water coolant contained inside the wicked as well as non-wicked copper heat pipes. The heights of the water meniscus range from 3.5" to 4.0" measured from the bottom end.
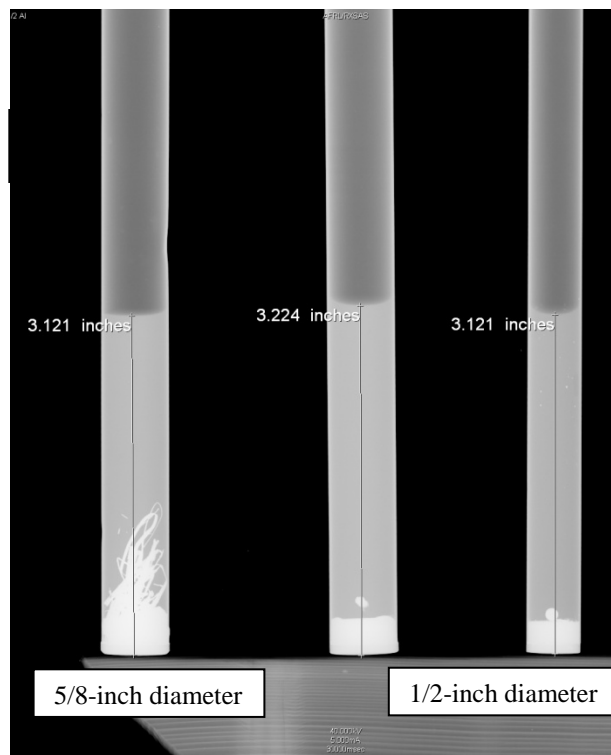
Figure 1: X-Ray Images of Aluminum Qu Tubes

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Wicked Water Heat Pipes   Non-wicked Water Heat Pipes
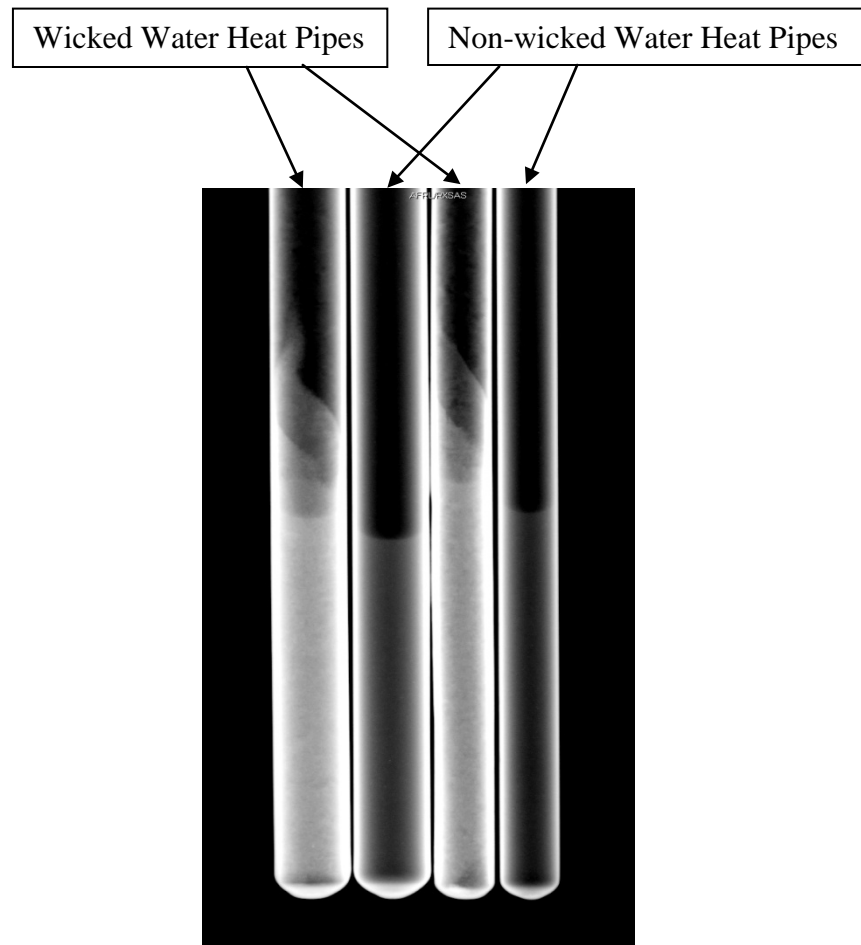
Figure 2: X-Ray Images of Copper Heat Pipes

3.2 IR Thermography Comparison of the Qu Tube with the Wicked Heat Pipe

In order to achieve a qualitative understanding of the operations of both Qu Tubes and water heat pipes, a total of twenty (20) IR video files were recorded. The detailed test conditions for these IR recordings are summarized in Table 1. Heating was provided by a heat gun, which expelled hot air to either the bottom of the evaporator ("bottom") or the approximate meniscus area ("meniscus"). The average meniscus locations were 3.12 inches from the bottom for the Qu-tube, 3.75 in. for the HP-wicking, and 3.33 inches for the HP-no wicking.

Figure 3 shows representative IR images extracted from the case identified in red-font in Table 1, which simultaneously imaged both the Qu Tube (left) and the wicked heat pipe (right) in nearly horizontal orientation (5-degree) under heating near the approximate meniscus areas.

With the heater on, at $t = 45$ sec (Fig. 3-A), the temperature near the meniscus area of the Qu Tube rises more rapidly than the rest, while the wicked heat pipe develops a more uniform temperature rise. It is believed that this d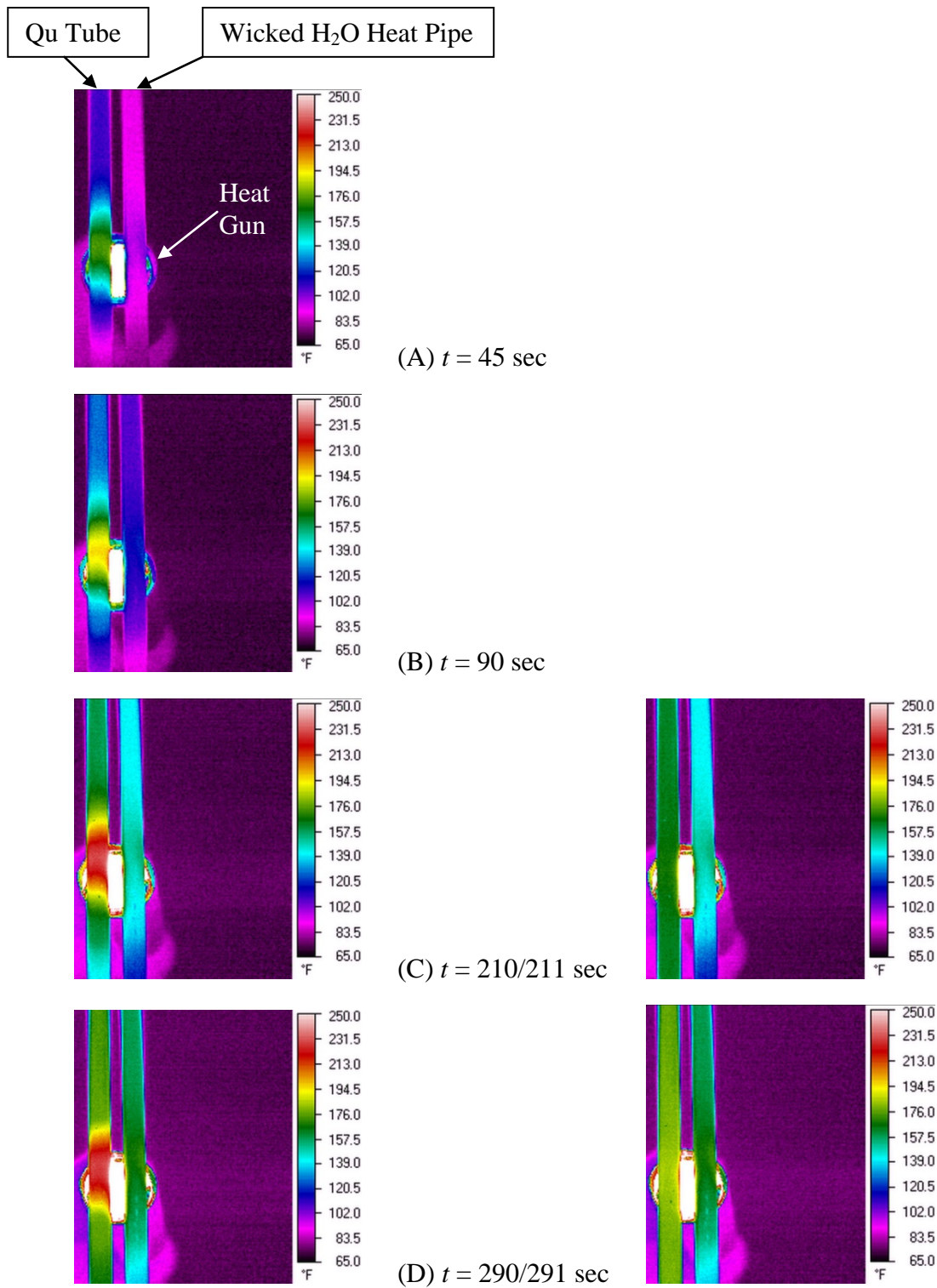istinction is attributed to the fact that the Qu Tube has no wick inside. For the tube surface area above the meniscus, the aluminum Qu Tube develops relatively higher temperature and seemingly steeper temperature gradients, in comparison with those of the copper heat pipe. This implies that the effective thermal conductivity of the Qu Tube may be lower than that of the heat pipe if we assume identical cooling heat transfer rate for both, which is proportional to the effective thermal conductivity multiplied by the temperature gradient along the tube surface. Similar observations prevail as time progresses showing the steeper temperature gradient and higher maximum temperature for the Qu Tube while more uniform and gradual temperature increases are observed for the heat pipe (Fig. 3-B).

When the temperature non-uniformity of the Qu Tube exceeds a certain limit (the left inset image of Fig. 3-C), the first very sudden surging of the working fluid is triggered and the inside is seemingly flooded with the fluid resulting in the uniform temperature distributions at least for a short period of time (the right inset image of Fig. 3-C). The surging continues repeatedly, but with progressively shorter intervals with reduced strength (Fig. 3-D). In contrast, the heat pipe raises the surface temperature gradually and uniformly ensuring far more stable operation.

Table 1: Experimental Matrix for Infra-Red (IR) Imaging

Dimension: 0.5"ϕ x 36"L	Qu-tube	HP-wicking	HP-no wicking
Qu-tube	V-bottom V-meniscus H-bottom H-meniscus		
HP-wicking	V-bottom V-meniscus **H-meniscus** H-meniscus (4 fps) NH-meniscus (4 fps)	V-bottom V-meniscus H-bottom H-meniscus	
HP-no wicking	V-bottom V-meniscus H-meniscus (4 fps) NH-meniscus (4 fps)	V-meniscus	V-bottom V-meniscus

V: Vertical orientation
H: Horizontal orientation

Qu Tube   Wicked H₂O Heat Pipe

Heat Gun

(A) *t* = 45 sec

(B) *t* = 90 sec

(C) *t* = 210/211 sec

(D) *t* = 290/291 sec

Figure 3: IR Images Of the Qu Tube (The Left Column in Each Image) and the Wicked Heat Pipe (The Right Column in Each Image) Simultaneously Heated By a Single Heat Gun

In summary, based on comprehensive observations of all the recorded image files, the Qu Tube responds more rapidly to heat input during start-up while the water heat pipe provides slow but more stable operation. In addition, the Qu Tube appears somewhat less effective in conduction heat transfer than the wicked water heat pipe. However, considering that the present experimental conditions, such as heating and cooling, were not rigorously controlled, a more concrete conclusion is deferred until a quantitative study under a controlled environment is completed. The detailed heat flux and temperature profiles for all of the selected test articles will be accurately measured.

3.3 Quantitative Characterization of both Qu Tube and Heat Pipe Operations

The experimental setup for quantitative characterization of the test articles has been designed, fabricated, and installed in-house at the Facility for Innovative Research in Structures Technology (FIRST) (Fig. 4). The test stand enables accurate setting of the predetermined orientation of the test articles (Fig. 5). The entire set up, including the heat pipe, the heater shoe with 24 electrical heater elements, and the cooling jacket of coiled copper tubing, is wrapped in insulation and placed inside the Cincinnati Sub-Zero (CSZ) environment control unit, which will be held at the heat sink coolant temperature (Fig. 6).

A data acquisition (DAQ) system has been developed to control the power to the heating elements and to monitor the temperature data from seventeen thermocouple probes of which, twelve probes are placed along the adiabatic region of the heat pipe, one placed at each end of the heat pipe, two measuring the inlet/outlet temperatures of the condenser flow path and the last one measuring the chamber temperature. The condenser coolant flow rate is detected by a digital flow meter and also monitored by the DAQ system (Fig. 7).

A number of necessary refinements and preparations have been conducted to facilitate quantitative characterization of the test articles. Three major tasks have been completed:

1. In order to meet the stringent requirements for temperature measurement accuracy, all of the industry-standard thermocouple probes (±1.0ºC measurement uncertainties) have been calibrated by elaborate laboratory processes to ensure ±0.1ºC uncertainties.

2. Erroneous detection of the coolant flow rate was identified and then corrected by inputting the correct flow meter calibration numbers for the LabView VI DAQ program.

3. Noise in the thermocouple probe readings was found to be caused by cross-talk between the heater power electrical current and the thermocouple probe voltages when they are mounted on the test article surfaces that are interfaced with the copper heater shoes via a pair of stainless steel inserts. The stainless inserts have been replaced by MACOR, a glass ceramic material with extremely high electrical resistance yet with acceptable thermal conductance as shown in Table 2 below.

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Table 2: Heater Insert Properties

Heater Insert Material	Thermal Conductivity (25ºC)	Electrical Resistivity
Stainless Steel	16 W/m·K	7.2×10^{-3} Ohms/m
MACOR	1.4 W/m·K	$> 10^{19}$ Ohms/m
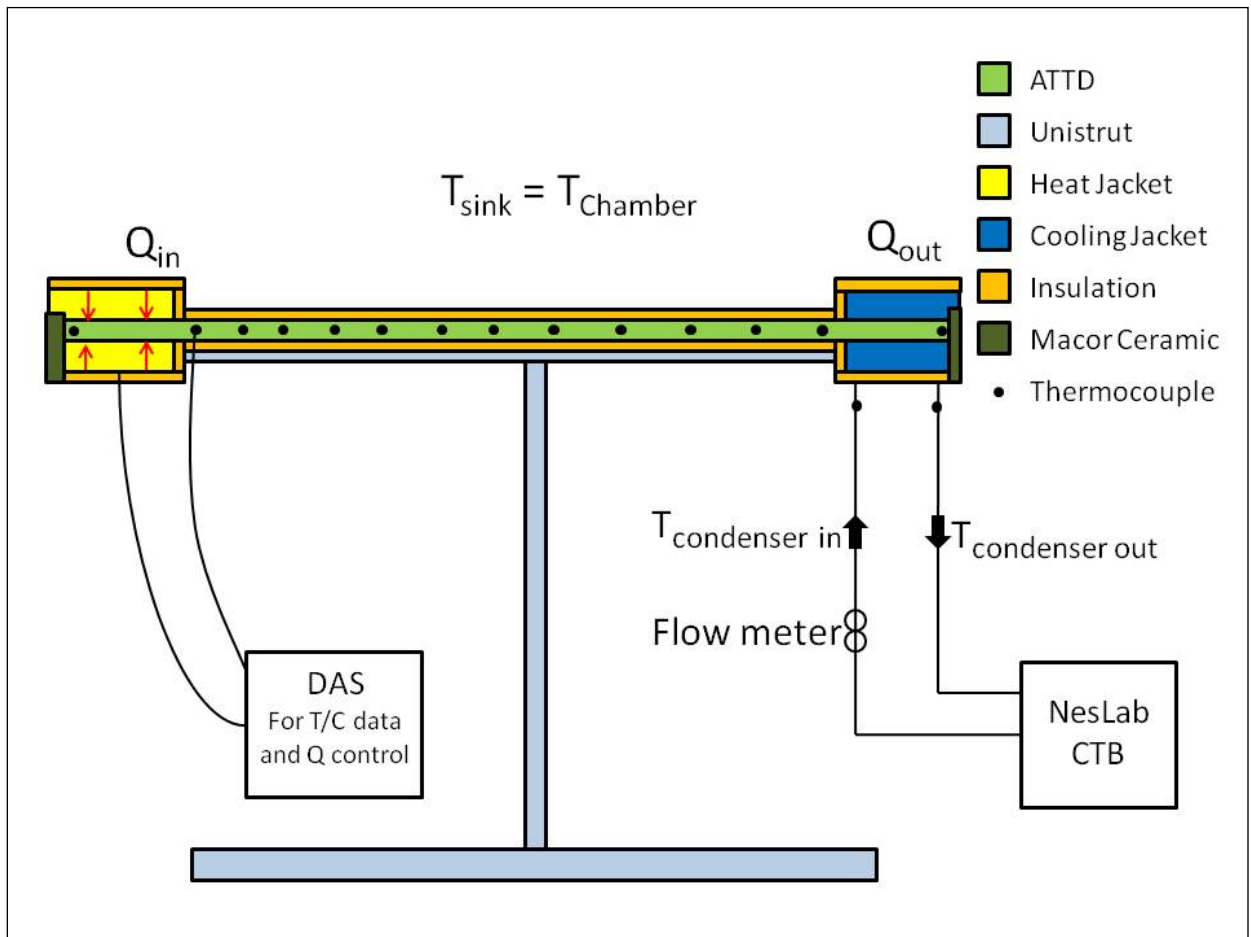
Figure 4: Schematic of the Experimental Set Up
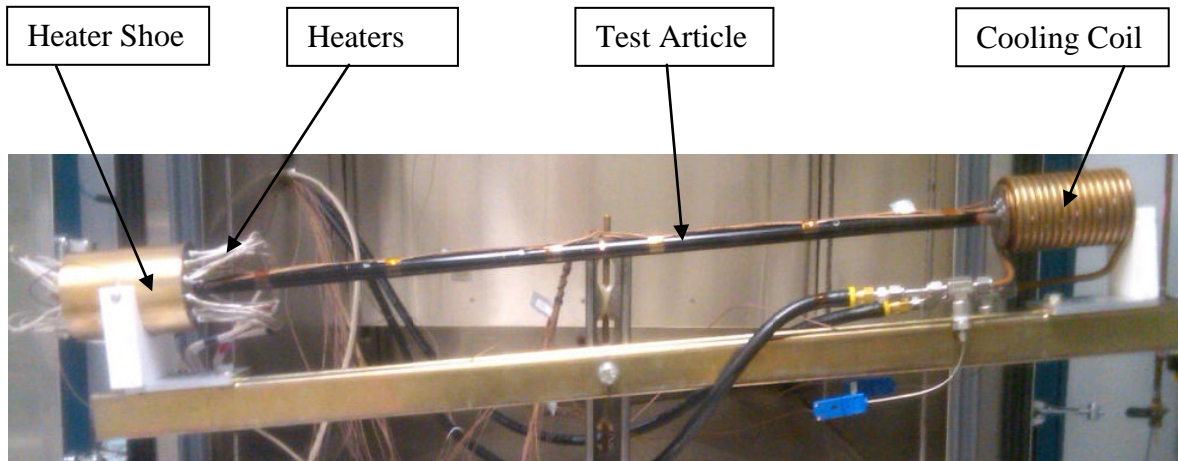
Figure 5: The Experimental Set Up To Adjust the Orientation of the Test Article

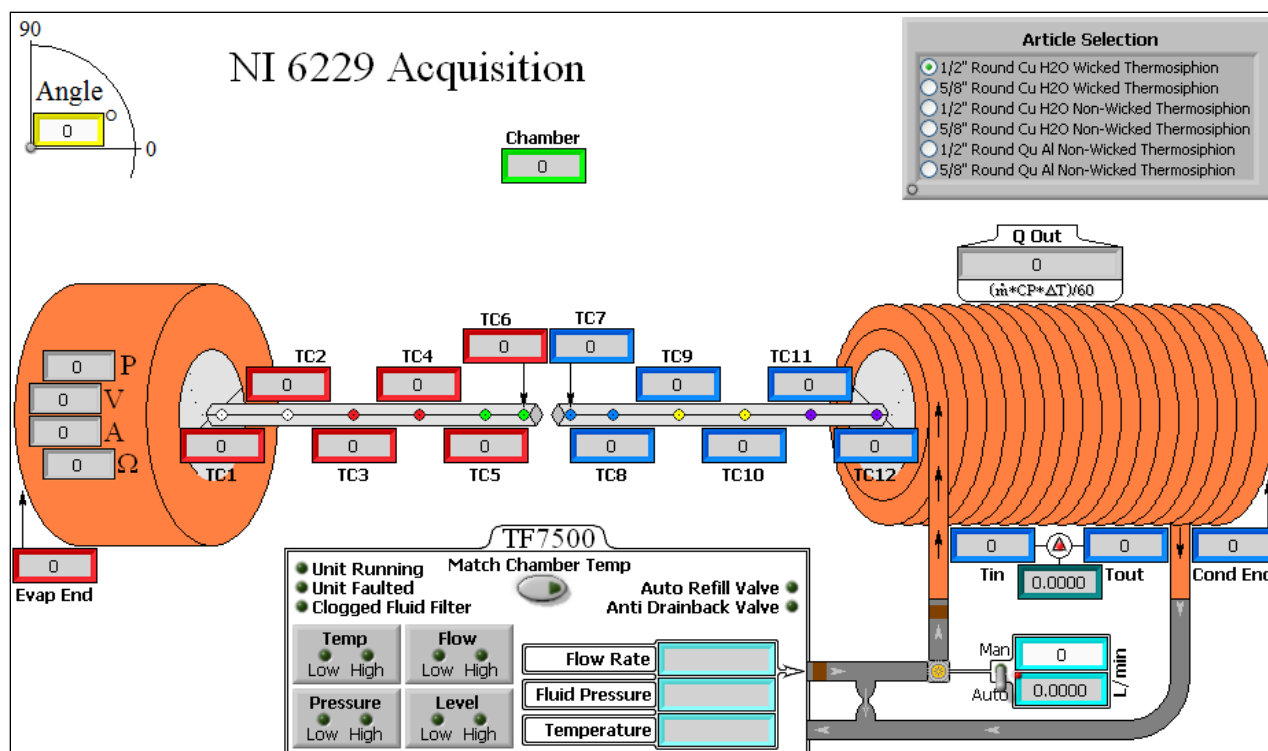**Figure 6:** Cincinnati Sub-Zero (CSZ) Chamber for Controlling Test Environment

Figure 7: Front-End Interface of the Labview VI Data Acquisition Program

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4.0   FUTURE DIRECTIONS

Upon completion of the aforementioned refinements and preparations of the DAQ system, a series of comparative studies between the Qu Tubes and the wicked heat pipes will be performed to validate the claims and performance of the Qu Tubes. The test matrix for planned experimental conditions is presented in Table 3.

Further, X-ray imaging will be conducted of the evaporator end of a Qu Tube in an inverted orientation (evaporator end above the condenser end) to prove or disprove the existence of a solid working solution inside. In addition, destructive characterization of tested Qu Tubes will determine their chemical composition.

Table 3: Test Matrix

Test Articles	5/8" diameter: Qu Tube vs. wicked heat pipe vs. non-wicked heat pipe		
	½" diameter: Qu Tube vs. wicked heat pipe vs. non-wicked heat pipe		
Orientation (degrees from horizontal)	5	1	-5
Heater Power Input (P)	P_{min} = 20 Watts P_{max} at dryout (ΔP = 10 Watts)	P_{min} = 20 Watts P_{max} at dryout (ΔP = 10 Watts)	P_{min} = 20 Watts P_{max} at dryout (ΔP = 10 Watts)
Coolant Chamber Temperature (°C)	10 50	10 50	10 50

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